

**FUSE STATE DETECTION CIRCUIT****FIELD OF THE INVENTION**

[0001] The invention relates to a fuse state detection circuit having a reference fuse and a  
5 fuse under detection, which reduce both layout mismatch and inconsistent electrical  
characteristics. Further, the invention relates to a fuse detection circuit that distinguishes a  
blown state of a fuse from an un-blown state of the fuse.

**BACKGROUND**

[0002] Programmable devices in complex electrical circuits are in widespread use for  
10 changing the circuits after fabrication. A laser fuse and an electrical fuse are two types of  
programmable devices. A laser fuse is programmed or blown by a laser tool before chip  
packaging. An electrical fuse can be programmed at any time by a fuse programming circuit  
within a packaged chip. The fuse programming circuit passes a high current through an  
electrical fuse to burn or program the fuse. The electrical fuse is said to be burned or blown  
15 when a current larger than a threshold current of about 5 mA flows through the fuse for a time  
period adequate to burn away the fuse, until the resistance of the blown fuse increases to a range  
of hundreds of kilo Ohms, indicating the fuse is open. After a fuse is blown, or programmed, the  
fuse state or fuse status is detected or sensed to determine that the fuse is blown or un-blown. A  
fuse state detection circuit senses the resistance value of the fuse to determine the fuse state. The  
20 fuse state detection circuit must detect whether a fuse is inadequately blown, to avoid detecting  
the inadequately blown fuse as being open.

**SUMMARY OF THE INVENTION**

[0003] According to the invention, a reference fuse replaces a reference resistor in a fuse  
detection circuit.

25 [0004] According to an embodiment of the invention, a reference fuse and a fuse to be  
detected are made with substantially the same materials, and have substantially the same  
dimensions and layout on a circuit board to reduce layout mismatch.

[0005] An embodiment of a detection circuit for indicating a blown state or an un-blown state of a fuse under detection has a fuse under detection and produces a fuse detection voltage corresponding to a detection current in the fuse under detection. The fuse detection circuit produces a reference voltage corresponding to a current in a reference fuse that is identical to the fuse under detection in its un-blown state. The reference voltage is between a fuse detection voltage corresponding to an un-blown state of the fuse under detection and a fuse detection voltage corresponding to a blown state of the fuse under detection. The fuse detection voltages, compared to the reference voltage, are distinguished from each other.

[0006] Further, an embodiment of a detection circuit has one or more fuse detection circuit parts each having a fuse under detection and a reference circuit part having a reference fuse identical to each fuse under detection in their un-blown states. The reference circuit part and each of the fuse detection circuit parts have respective current mirror transistors. The current mirror transistors of fuse detection circuit parts are smaller than the current mirror transistor in the reference circuit part.

[0007] Another embodiment of the present invention is a method of detecting a blown state or un-blown state of a fuse under detection; by generating a fuse detection voltage in a fuse detection circuit part, the fuse detection circuit part having the fuse under detection; and by generating a reference voltage in a reference circuit part, the reference circuit part having a reference fuse identical to the fuse under detection in its un-blown state; and comparing the reference voltage and the fuse detection voltage to determine whether the fuse under detection is blown or un-blown.

[0008] Another embodiment of the present invention is a method of making a fuse detection circuit; by fabricating a fuse detection circuit part having a fuse under detection; and fabricating a reference circuit part having a reference fuse identical to the fuse under detection in its un-blown state; and fabricating a comparator for comparing a reference voltage in the reference circuit part with a voltage in the fuse detection circuit part to determine whether the fuse under detection is blown or un-blown.

[0009] Embodiments of the invention will now be described by way of example with reference to the accompanying drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. 1 is a prior art fuse state detection circuit.

5 [0011] FIG. 2 is a prior art fuse state detection circuit.

[0012] FIG. 3 is a fuse state detection circuit according to one embodiment of the invention.

[0013] FIG. 4 is a diagram of a reference component, also referred to as, a reference circuit part or reference circuit portion according to one embodiment of the invention.

10 [0014] FIG. 5 is a diagram of a fuse state detection circuit part or fuse state detection circuit portion according to one embodiment of the invention.

[0015] FIG. 6 is a diagram of a prior art comparator.

[0016] FIG. 7 is a diagram of a circuit having examples of multiple fuse state detection circuits that are capable of being driven by one reference component according to one  
15 embodiment of the invention.

#### DETAILED DESCRIPTION

[0017] Fig. 1 discloses a prior art fuse state detection circuit (100) having a reference resistor (102), indicated by its reference resistance  $R_r$ , for comparing with a fuse resistance  $R_x$  of a fuse (104) to determine the state of the fuse (104)

20 [0018] The input voltage to the reference resistor (102) and the fuse (104) is  $V_{DD}$ .

[0019] The state of the Fuse is determined by the fuse resistance  $R_x$ , wherein,

$R_x = R_i$  for the initial resistance of an un-blown Fuse, and

$R_x = R_b$  for the resistance of a blown Fuse, and

$$R_i < R_b$$

$V_F = V_{Fi}$  for the detected voltage of an un-blown Fuse, and

$V_F = V_{Fb}$  for the detected voltage of a blown Fuse.

[0020] The sensing margin is denoted as  $\Delta V$ , the voltage difference between that of the un-blown fuse and that of the blown fuse.

$$\begin{aligned} [0021] \quad \text{Thus, } \Delta V &= V_{Fi} - V_{Fb} = \{R/(R_i + R) - R/(R_b + R)\} \{V_{DD}\} \\ &= (R_b - R_i)(V_{DD}) / R(1 + R_i/R)(1 + R_b/R) \end{aligned}$$

[0022] When a reference resistance  $R_r$  is selected in a range of  $R_i < R_r < R_b$ , then make  $V_R = V_{Fb} + \Delta V/2$ , such that  $V_{Fi} > V_R > V_{Fb}$ .

[0023] The circuit (100) has a comparator (106) for comparing the voltages  $V_R$  and  $V_F$  to produce an output voltage "OUT" to indicate  $V_{Fi} > V_R$  for the detected voltage of an un-blown fuse, or to indicate  $V_R > V_{Fb}$  for the detected voltage of a blown fuse.

[0024] The circuit (100) of Fig. 1 has a first resistor  $R$  and the reference resistor  $R_r$  in a reference part of the circuit (100), and a second resistor  $R$  and the fuse  $R_x$  in a detection part of the circuit (100). Each time a detection operation is performed, the input voltage  $V_{DD}$  causes a reference electrical current to flow through the first resistor  $R$  and the reference resistor  $R_r$  in the reference part of the circuit (100). Further, the input voltage  $V_{DD}$  causes a detection current to flow through the second resistor  $R$  and the fuse  $R_x$  in the detection part of the circuit (100). This current flows in response to the input voltage  $V_{DD}$  cause permanent electrical characteristics shifts of the resistors  $R$ ,  $R$ ,  $R_r$  and  $R_x$ . Any differences in the electrical characteristics among the resistors  $R$ ,  $R$ ,  $R_r$  and  $R_x$  at the beginning of a detection operation will cause different electrical characteristics shift. If the material or geometric layout of the fuse  $R_x$  is different from that of the resistors  $R$ ,  $R$  it may have a different electrical characteristics shift than that of the resistors  $R$ ,  $R$  after a number of fuse detection operations, which may cause incorrect detection of the fuse state. If the material or geometric layout of the fuse  $R_x$  is different from that of the reference resistor  $R_r$ , it may have a different electrical characteristics shift than that of the reference

resistor  $R_r$ , after a number of fuse detection operations, which may cause incorrect detection of the fuse state.

[0025] Fig. 2 discloses another prior art fuse state detection circuit (100') having a reference resistor (102') of a reference resistance  $R_r$ , for comparing with the resistance of a fuse (104') having a fuse resistance  $R_x$ , to determine the state of the Fuse.

[0026] The input voltage to the reference resistor (102) and the fuse (104) is  $V_{DD}$ .

[0027] The state of the fuse is determined by the fuse resistance  $R_x$ , wherein,

$R_x = R_i$  for the initial resistance of an un-blown fuse, and

$x = R_b$  for the resistance of a blown fuse, and

10  $i < R_b$

$F = V_{Fi}$  for the detected voltage of an un-blown fuse, and

$F = V_{Fb}$  for the detected voltage of a blown fuse.

and  $I_s$  = reference current in each of  $R_r$  and  $R_x$ .

[0028] The sensing margin (voltage difference between that of un-blown Fuse and blown Fuse) is:

$$\Delta V = V_{Fi} - V_{Fb} = (R_b - R_i)(I_s) = (\Delta R)(I_s)$$

[0029] Thus, the sensing margin is proportional to both  $I_s$ , the reference current, and  $\Delta R$ , the difference between the resistance of the blown fuse and the resistance of the un-blown fuse.

20 [0030] When a reference resistance  $R_r = (R_i + R_b)/2$  then it makes

$$V_R = (V_{Fi} + V_{Fb})/2$$

[0031] The circuit (100') has a comparator (106') for comparing the voltages  $V_R$  and  $V_F$  to produce an output voltage "OUT" to indicate  $V_{Fi}/2 > V_R$  for the detected voltage of an un-blown fuse, or to indicate  $V_R > V_{Fb}/2$  for the detected voltage of a blown fuse.

[0032] Each time a detection operation is performed, the input voltage  $V_{DD}$  causes a reference electrical current  $I_s$  to flow through the reference resistor  $R_r$  in the reference part of the circuit (100). Further, the input voltage  $V_{DD}$  causes a detection current  $I_s$  to flow through the fuse  $R_x$  in the detection part of the circuit (100). These current flows in response to the input voltage  $V_{DD}$  cause permanent electrical characteristics shifts of the resistors  $R_r$  and  $R_x$ . The circuit (100') of Fig. 2 eliminates the first resistor  $R$  of Fig. 1 from a reference part of the circuit (100'). Further, the circuit (100') of Fig. 2 eliminates the second resistance  $R$  of Fig. 1 from a detection part of the circuit (100'). Thus, the circuit (100') of Fig. 2 has a reduced number of resistors that would undergo electrical characteristics shifts during a detection operation. The circuit (100') of Fig. 2 has only the resistors  $R_r$  and  $R_x$  that would undergo electrical characteristics shifts during a detection operation. However, any differences in the electrical characteristics among the resistors  $R_r$  and  $R_x$  at the beginning of a detection operation will cause different electrical characteristics shift during the detection operation. If the material or geometric layout of the fuse  $R_x$  is different from that of the reference resistor  $R_r$ , it may have a different electrical characteristics shift than that of the reference resistor  $R_r$ , after a number of fuse detection operations, which may cause incorrect detection of the fuse state.

[0033] Fig. 3 discloses an embodiment of a fuse state detection circuit (300) according to one embodiment of the invention. A reference circuit part or reference circuit portion (302) outputs a reference voltage  $V_R$ . Another embodiment of a reference circuit part (302') is discussed further below with reference to Fig. 4. With continued reference to Fig. 3, the circuit (300) has a reference fuse (304) with a reference resistance  $R_r$ , for comparing with a fuse resistance  $R_x$  of a fuse (306) of a fuse state detection circuit part or portion (308) to determine the state or status of the fuse (306). The circuit (300) has a comparator (310) for fuse state detection, or fuse status detection, by comparing the output, reference voltage  $V_R$  of the reference circuit (302) and the output detection voltage  $V_F$  of the fuse state detection circuit (308). According to the invention, the fuse (306) can be blown by at least passing an electrical current of sufficient magnitude to cause the fuse (306) to open, or by subjecting the fuse (306) to a laser output to cause the fuse (306) to open.

[0034] The state or status of the fuse is determined by the fuse resistance  $R_x$ , wherein,

$R_x = R_i$  for the initial resistance of an un-blown Fuse, and

$R_x = R_b$  for the resistance of a blown Fuse, and

$R_i < R_b$

Fuse resistance:  **$R_x$**

5  **$R_x = R_i$**  the initial resistance of un-blown fuse.

**$R_x = R_b$**  the resistance of blown fuse.

**$R_i < R_b$**

**$I_R$**  : Reference current

**$I_D$**  : Detective current

10 **[0035]** The sensing margin is the voltage difference between the un-blown and blown fuse states:

$$\Delta V = V_{Fi} - V_{Fb} = (R_b - R_i) \cdot I_D = \Delta R \cdot I_D$$

**[0036]** Thus, the sensing margin is proportional to a detection current  **$I_D$**  and a difference between a blown and un-blown fuse states.

15 **[0037]** The reference fuse is chosen with a resistance  **$R_r = R_i$** , and a reference current  **$I_R$**  to make  **$V_R = (V_{Fi} + V_{Fb}) / 2$** .

**[0038]** Accordingly, by locating the value of  **$V_R$**  between  **$V_{Fi}$**  and  **$V_{Fb}$** , then, the blown, blown or programmed state of the fuse (306) can be readily identified and distinguished from the un-blown, un-blown or un-programmed state. The output signal of the comparator (310) indicates whether the detection voltage  **$V_F$**  is either greater than, or less than, the reference voltage  **$V_R$** .

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$$R_r \cdot I_R = R_i \cdot I_R = (R_b + R_i) \cdot I_D / 2$$

$$I_R = 1/2(1 + R_b/R_i) \cdot I_D$$

Due to  $R_b > R_i$ , such that  **$I_R > I_D$**

For example

If  $R_b = 1.2 R_i$  then  $IR = 1.1 \cdot ID$

If  $R_b = 1.5 R_i$  then  $IR = 1.25 \cdot ID$

If  $R_b = 2 R_i$  then  $IR = 1.5 \cdot ID$

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[0039] In the circuit (300) of Fig. 3, a reference fuse (304) is the reference, and not a resistor, as in the prior art. The reference fuse (304) and the un-blown fuse (306) to be detected are substantially identical structures that have substantially identical electrical characteristics. They are fabricated with substantially the same materials, and have substantially the same dimensions and lay out on a circuit board (312), which reduces lay out differences and inconsistent characteristics shift from different materials that would contribute to electrical mismatch. For example, the reference fuse (304) and the fuse (306) are fabricated of the same material, including and not limited to, polysilicon, and have substantially the same length, width and thickness on the circuit board (312).

15 [0040] The identical reference fuse (304) and the fuse (306) undergo the same changes in electrical characteristics after undergoing a number of fuse detection operations. Performing a number of fuse state detection operations makes the reference fuse (304) and the fuse (306) undergo changes in electrical characteristics. According to the invention, since the reference fuse (304) and the fuse (306) have the same structure, materials and layout, they undergo the same shifts in electrical characteristics after undergoing a number of fuse state detection operations, which means that their shifts in electrical characteristics do not change relative to each other. A change in electrical characteristics of the reference fuse (304) is compensated by the same change in electrical characteristics of the fuse (306). Changes in electrical characteristics of the reference fuse (304) and the fuse (306), after undergoing a number of fuse detection operations, do not introduce errors in detection of the fuse state. Thus, the relative values of  $R_r$  and  $R_i$  control the fuse state detection without additional electrical mismatch that would be contributed by differences in structure and layout of the reference fuse (304) and the fuse (306).

[0041] Fig. 4 discloses an embodiment of the present invention for a reference circuit part or portion (302'). The reference circuit part (302') generates a reference voltage and a reference current in response to an input fuse detection enable signal. Fig. 4 discloses the reference circuit part (302') with a reference fuse (304') at an input voltage HV and a reference current  $I_R$  and output voltage  $V_R$ . The reference fuse (304') is in series with an n-channel MOS transistor M2 (400) that is controlled by an input signal, a fuse detection enable signal, FDEN signal, to switch on/off the circuit (302). An n-channel MOS transistor M3 (402) is for establishing a bias voltage  $V_{NBIAS}$  by MOS transistor M3 (402). When FDEN goes high M2 is turned on and enables the reference component or circuit part (302) to establish a reference current  $I_R$  and transfer the reference current  $I_R$  to a voltage bias  $V_{NBIAS}$  by MOS transistor M3 (402). The reference component or circuit part (302') outputs a reference voltage  $V_R$  for comparing with a detected fuse voltage to sense the fuse state of the fuse, such as, the fuse (306) of Fig. 3, or such as, the fuse (306') of Fig. 5. After the fuse state is sensed fully out, for example, by the comparator (310) of Fig. 3, or by the comparator 310') of Fig. 5, then FDEN goes low to shut off the current path by turning off the MOS transistor M2, which extinguishes all current in the circuit (302).

[0042] Fig. 5 discloses another embodiment of the present invention for a fuse state detection circuit (308') having a fuse programming switch MOS transistor M4 (500) controlled by an input signal PROG. The fuse programming switch MOS transistor M4 (500) is turned on by the input signal PROG to sink to ground or earth electrical potential a large current to burn the fuse (306''). According to the invention, the fuse (306') can be blown by at least passing an electrical current of sufficient magnitude to cause the fuse (306') to open, or by subjecting the fuse (306) to a laser output to cause the fuse (306') to open.

[0043] In Fig. 5, the fuse (306') of the circuit (308') is in series with an n-MOS transistor M6 (502) is controlled by the FDEN signal, similarly as is the transistor M2 (400) of Fig. 4. The FDEN signal turns on both the transistor M6 (502) and a series MOS transistor M7 (504). The transistor M7 (504) is biased by  $V_{NBIAS}$  by MOS transistor M3 (402) of the reference circuit part (302') of Fig. 4. The transistor M7 (504) is slightly smaller than the transistor M3 (402), i. e.,  $M7 < M3$ , which establishes a detective current  $I_D$  through the fuse (306') to detect the fuse state

or status. The detective current  $I_D$  is smaller than the reference current  $I_R$  according to the equation:

$$I_R = (1/2)(1 + R_b/R_i)(I_D)$$

[0044] An embodiment of the invention has a current mirror structure. The MOS transistor M3 of the reference circuit (302') of Fig. 4, and the MOS transistor M7 (504) of the fuse state detection circuit (308') of Fig. 5, are current mirror transistors. The current mirror structure establishes a detective current  $I_D$  through the fuse (306') to detect the fuse state or status. Thus, a fuse voltage  $V_F$  is created by current  $I_D$  through the fuse (308'). The blown or un-blown state or status of the fuse (308') is sensed by a comparator (310') that compares the detected fuse voltage  $V_F$  with the reference  $V_R$ . The comparator (310') produces an output signal that indicates whether reference  $V_R$  is either, greater than, or less than, the detected fuse voltage  $V_F$

[0045] Fig. 6 discloses a prior art, practical comparator (600), of which  $V_R$  and  $V_F$  are differential inputs. RDEN is a comparator enable signal. RDEN can enable the comparator, if RDEN goes high to turn on MOS M10 and turn off equalizer MOS M15 and M16. When  $V_F$  is higher than  $V_R$ , the VGS of M8 is larger than M9 so that the pull low current of M8 is larger than M9 thereof the pull low speed of terminal /OUT is faster than terminal OUT. By sensing circuit M11-M14, the state of terminal /OUT will be developed to low and the state of OUT will be developed to high. When  $V_F$  is lower than  $V_R$ , the VGS of M8 is smaller than M9 so that the pull low current of M8 is smaller than M9 thereof the pull low speed of terminal /OUT is slower than terminal OUT. By sensing circuit M11-M14, the state of terminal /OUT will be developed to high and the state of OUT will be developed to low.

[0046] Fig. 7 is a circuit diagram of examples of multiple external fuse state detection circuits (308'), (308') and (308'), for example, a series, 1, 2, ...N., in number, that are capable of being driven by  $V_R$  and  $V_{NBias}$  by one reference component or one reference circuit part (300), as disclosed by Fig. 3, and by the fuse detection enable signal, FDEN signal, and the comparator enable signal RDEN signal. Thus, the invention includes, and is not limited to, one or more fuse state detection circuits (308') in combination with a reference circuit part (300).

**[0047]** Although the invention has been described in terms of exemplary embodiments, it is not limited thereto. Rather, the appended claims should be construed broadly, to include other variants and embodiments of the invention, which may be made by those skilled in the art without departing from the scope and range of equivalents of the invention.